# Project (Draft) Report

- Project Group 5: Digital Reading -

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# Abstract

This report has been carried out as part of the course AG2800 - Life Cycle Analysis at the Royal institute of Technology (KTH), Stockholm, during the autumn of 2016. Students enrolled at KTH receive a fair share of course literature through the internet. When receiving the reading instructions for a course, the student can choose if he or she prefers to print the required pages at KTH or read the literature from their laptop. Many students take this decision based on preferences; they may have an personal assumption towards which alternative is the most environmental friendly. This report aims to answer which of the two alternatives, digital reading versus printing, is the most preferable from an environmental perspective based on the lifecycle. Therefore, a comparative LCA was conducted, using the computer program SimaPro and literature studies, in order to visualise the impacts of the systems side by side. The functional unit was set to read 100-A4 pages of course litterature in PDF-format.

The LCA was divided in two parts accordingly to the two alternatives, option one being the digital reading, option two being the printed reading. In alternative one, the importance of the reading speed and energy usage was discovered, a sensitivity analysis of this factor was conducted. The lifecycle process of digital reading consists of the inputs of a laptop and electricity, and an output in the form of a waste scenario for the laptop and packaging. The second alternative, consisted of the following inputs and outputs; printer, electricity, toner, paper and the waste scenarios for the toner module and the paper. The LCA calculation results showed that, for both alternatives, freshwater eutrophication, freshwater ecotoxicity, human toxicity and marine ecotoxicity were the impact categories that have the highest influence. The result also showed that the digital reading scenario was worse for the environment compared to the printing. However the reading speed did play a large role in the outcome and the following recommendation is made: if the 100 pages are to be read carefully or several times do print the PDF, if the student is just skimming through the 100 pages do not print.

# Contents

# 1. Introduction

Throughout an academic term, students have to read large amounts of written material, which is often provided to them in digital PDF format - either in the form of individual book chapters or journal articles. Students then have the choice to read the provided material on-screen using their laptop, or print the documents and read them on paper. Looking at the cumulative required reading - for instance, for all students in a certain course - this amounts to significant amounts of printed pages or computer hours. Therefore, identifying which technique creates lower environmental impacts is highly relevant, especially for students in the area of sustainability.

Generally speaking, comparative LCAs for digital reading have previously been carried out. However, these LCAs have been concerned with leisurely reading (Ahmadi Achachlouei 2015), a comparison of ebooks to printed books (Kozak 2003), or printing in an office setting (Deetman and Odegard 2009). None of these studies truly apply in the academic setting described above: students cannot simply decide not to read large portions of the provided material, as subjects in the first study can, and the academic setting does not include the transport-related disadvantages of bound books as in the second study. In addition, the scenario described above does not make use of digital e-book reading devices, as both the second and the third study do.

Therefore, this report aims to clarify, for the context of mandatory academic reading and on-campus printing, how large the environmental impacts of on-screen reading are compared to printing PDF files in quantities typical for academia. For the purposes of this report, students were using SimaPro (Version 8.0; Pré Consultants, 2015) in combination with the Ecoinvent 3.3 database as implemented in SimaPro 8 .

# 2. Goal of the study

In accordance with the research gap previously described, this LCA attempts to answer the following research question: What is the environmental impact of reading a pdf file on-screen as opposed to printing and reading it on paper? This question was chosen out of a personal interest of the authors, and due its significance for university-level students in a wider context.

The research compares two different types of reading (on-screen and printing), and thus employs a comparative LCA. Since the authors are aiming to define environmental impacts caused by actions within the current status quo of the socio-technical system, the LCA research performed is an accounting LCA. The report will therefore be using average (as opposed to marginal) data for the environmental effects under consideration.

The intended audience of this LCA includes both KTH and students enrolled at the university. It is intended to provide KTH with the data necessary to issue correct recommendations as to the most environmentally friendly reading options. More specifically, the results of this study could inspire an official guideline towards more sustainable behavior when reading PDFs, replacing the worn-out and uninformative phrase “Mind our forests - only print this text if you need to.”

More broadly speaking, however, one could easily imagine that the results of the LCA could be more broadly usable if one allows for slight modifications to account for varying local conditions (such as the energy mix and transportation distances). In this case, the results of this report may be of interest for academic personnel and students on a global scale.

# 3. Scope of the Study

## 3.1. Functional Unit

In a first step, the authors have decided to use a defined number of “pages to be read” as the functional unit. This unit of measurement was chosen both because of its practicality and due to its functionality: a page of material will allow for the transfer of the same amount of knowledge independent of the reading mode (digital or printed).

Most students need to cover several hundred pages of reading within each of their courses. Additionally, the uncertainty in many calculations (eg: energy consumption per printed page) decreases with the number of pages considered. Out of these reflections, the authors finally defined the functional unit as follows: Reading 100 pages of an A4-format PDF document, either by printing and reading on paper, or by reading on-screen on a laptop.

## 3.2. System Boundaries

In order to consider all environmental impacts associated with either technique, the authors decided to include all devices used[1]. Flowcharts representing these system boundaries for digital and paper-based reading can be found in Figure 1 and Figure 2, respectively.

Due to constraints on the availability of data for the disposal of a laser printer, this stage was not included in the LCA despite forming part of the original conceptual flowchart. This leads to the final inclusion of the following list of processes:

**Digital Reading**

1. Production of the Laptop
2. Production of Electricity
3. Usage of Laptop (during reading)
4. Disposal of Laptop

**On-paper reading**

1. Production of the Printer
2. Production & Disposal of the Paper
3. Production of Toner
4. Printing process

[1] Allocation issues arising from this decision will be discussed in chapter 4.

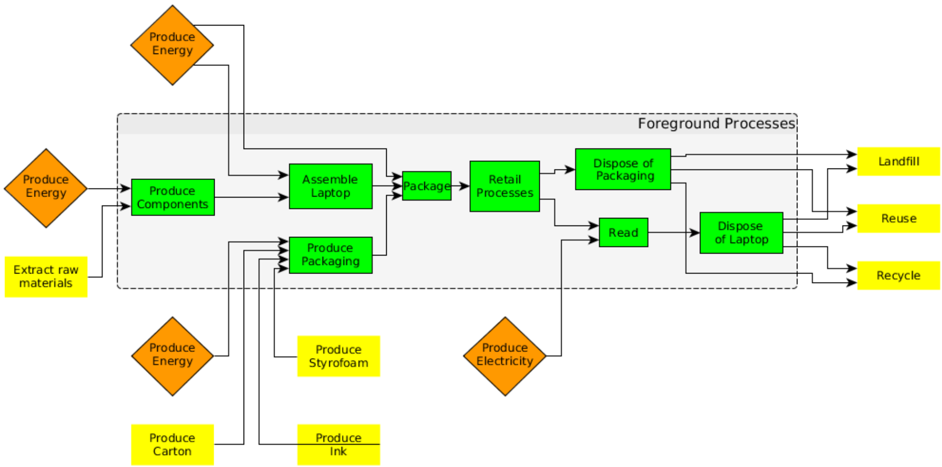



Figure 1.: Conceptual flowchart - System boundaries for digital reading

Within the digital reading system, the mentioned processes cover a full cradle-to-grave perspective, including mining of raw materials as well as a full recycling/waste handling process scenario for the laptop.

Geographical boundaries have not been set for the production processes of the laptop. Since most of the metals used within the production of this product come from distant and widely dispersed countries (Friends of the Earth Netherlands/Milieudefensie et al. 2015), they must be shipped back and forth before finally arriving at the customer - making it rather impossible to include a boundary. However, the geographic boundary for the usage phase was set to include Sweden only. This is based on the fact that most reading by KTH students will be completed within Sweden, and impacts data through the energy mix selected for the usage phase.

With respect to the time horizon, it is easy to see that data on production, usage and waste should be quite up-to-date due to technological developments in EEE. Similar demands on the data quality hold for information about the energy mix. In addition, these restrictions mean that the results derived from this LCA will most likely be outdated within a few years, since new technological developments will render energy consumption estimates as well as other crucial data severely outdated. No impacts in the far future (for instance, from land-filling) are considered, since the waste scenario seems to suggest that all materials are recycled.

Within the paper reading system, a limited cradle-to-grave approach is taken. On the "cradle"-side, the extraction of raw materials for the printer and paper are included, but activities for the toner powder start with the reception of raw material at the factory gate. On the "grave"-end, there is a full disposal scenario for paper. However, the printer does not include a waste scenario due to severe lack of available data, while toner powder is only considered until the end of production.

A geographical boundary for the printer, including the toner cartridge and the toner powder, is not set during the production phase[2]. The geographical boundary for paper production is set within the borders of Europe. As mentioned above in the digital reading system, this LCA is done for students at KTH. Therefore, we assume that the printing process itself is carried out in Sweden, and a country-specific energy mix is chosen.

[2]The same characteristics apply as described above for the computer

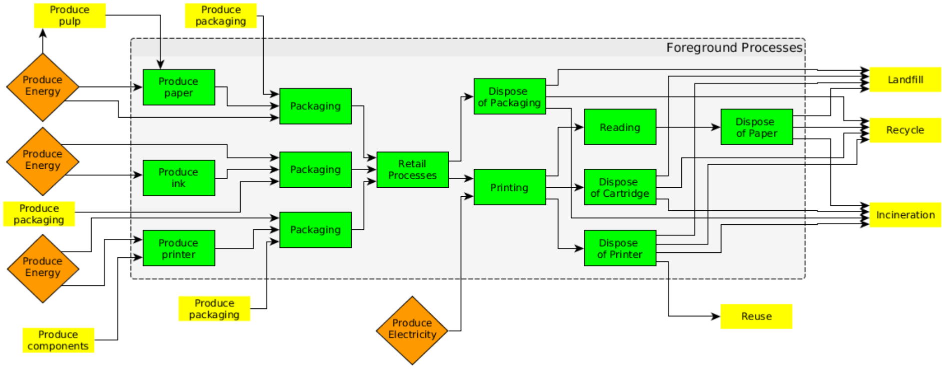



Figure 2.: Conceptual flowchart - System boundaries for on-paper reading

| **Item** | **Allocation reason** | **Allocation criterion** |
|---|---|---|
| Factories | Multi-output | Directly adopted from model |
| Transport | Multi-function | Directly adopted from model |
| Energy mix | Multi-input | Directly adopted from model |
| Printer | Multiple users | Number of pages |
| Laptop | Multi-function | Lifetime percentage |

Table 3.1.: Allocation criteria for multiple allocation issues

When looking at the time horizon in relation to the paper-reading system, data on production, usage and waste should be quite current due to technological developments in EEE; the same applies for information on the energy.

Originally, for both systems, many parts were thought of as potential cut-offs, quite simply because of the assumption there would be no information available. Examples include electrical components making up less than 5% of the total mass of the electronic devices. However, the model already excluded most of the smaller components, and the authors decided not to introduce any further restrictions on the data. Some cut-off with respect to transportation data were made: transportation from the store to the final consumer was not included in the model. This is based on the dual argument that

1. Most people now buy consumer electronics online; in which case the device is delivered directly to them, not to a store. Similarly, KTH is likely to buy printers directly from the producer, without the intermediate of a retail store.

2. For both the printer and the laptop models used, transport to the store was already included.

Since the "store" is likely modeled to be close to the final consumer, and we assume that this intermediate retailing step does not take place, the transport to the store can be assumed to be transport to the customer's home. The error introduced through this assumption should be negligible in relation to over 3000 km of sea transport already considered.

Several allocation issues had to be treated within this LCA; a more detailed explanation of the calculation involved in any allocation carried out by the authors can be found in chapter 4.

## 3.3. Assumptions and Limitations

### 3.3.1. General

- No environmental impacts are generated by the maintenance of the laptop and the printer.
- Every student has access to both options - availability does not influence the students' choice, and no-one chooses to print at home.
- Students can use terminals at university to print, which cannot be used for reading and run all day, every day, independently of actual usage. Therefore, environmental impacts from computer usage related to printing are not included in the LCA.
- The reading materials are distributed to the students through an online platform such as Bilda. Therefore, the digital version of the article already exists for both scenarios, and environmental impacts related to this digital version (cloud storage,...) are not considered.
- KTH uses the standard energy mix in Sweden for printing; so does everyone charging their laptop.

### 3.3.2. Digital Reading

- The purchase of a laptop is reasonable for students, and is not carried out solely for the purpose of reading materials.
- Students can concentrate very well, and are consistent in their concentration levels. A student will stop reading when they feel like they will lose focus. Therefore, we assume concentration is infinite and does not affect the reading time.
- The laptop runs in a normal usage pattern, with a few extra programs on the background (such as wifi-connection) but no major activity (watching videos). The settings are not optimized for extremely low energy usage.
- The life span of a laptop is not influenced by the sort of actions taken on it. Therefore, reading for ten hours "uses up" as much of the laptop as ten hours of idling or video watching.
- A laptop will not break down before its expected end of life.
- The laptop model found in SimaPro will be representative compared to current market-models. Even though it is an older model, we assume that while the screens increased energy usage, processors decreased theirs and conversion efficiency increased. Both technological improvements will level out differences in energy efficiency. In addition, there are no significant changes in terms of materials used, toxicity, et cetera.
- Research with respect to reading speeds is applicable to digital digital reading.
- The number of words per page (in a scientific article) remains approximately the same across different academic disciplines.

### 3.3.3. Paper reading

- Students exclusively use the printer at KTH, not a printer at home.
- The waste disposal technology with respect to paper in Quebec, Canada is similar to the technology used in Sweden.
- 100% of the paper ends up in the chosen disposal scenario.
- Model items in the EcoInvent Database, such as paper and printer, are representative of the actual items in use.

## 3.4. Impact Categories and Impact Assessment Method

ReCiPe constitutes an indicator approach for Life Cycle Inventory results. As seen in SimaPro, the list of results can be long and complex. Thus, they has to be interpreted and transformed into a small number of indicators which clarify the arising environmental impact category (Consultants 2016b).

There are different impact assessment methods available in the ReCiPe indicator approach. Those methods focus on results at different stages in the cause-effect chain of the analyzed life cycle. In this case, the impact assessment method midpoint has been chosen over the endpoint assessment method because the first looks at earlier stages in the cause-effect chain, e.g. the increase of chemicals in a lake may be one of the results. On the other side, the assessment method endpoint would take a look at the following effects on fish in this lake, e.g. their extinction. The midpoint method uses 18 indicators, such as climate change or natural land transformation, to link causes to effects whereas the endpoint method uses only three indicators (for instance, human health).

Thus, the endpoint indicator method may be easier to communicate, as it is more comprehensive and doesn't require much knowledge about the environmental impacts, but it has a much higher level of statistical uncertainties. The midpoint method, in contrast, has a much larger number of impact categories, and its focus on early stages in the cause-effect chain require some pre-existing knowledge about those impacts. Nonetheless, a much more detailed result is available which can help to identify trade-offs in different categories (Brilhuis-Meijer 2014). All in all, the midpoint method can be seen as a more problem oriented approach (Consultants 2016a).

Furthermore, different cultural perspectives can be chosen in the ReCiPe indicator approach. Those perspectives represent different choices regarding, for example, the timeframe of the impacts, or expectations whether future technologies can mitigate future environmental impacts (Consultants 2016b). The chosen perspective, hierarchist, is based on the common policy principle. It's timeframe of 100 years is also referenced in the ISO14044 standard on LCAs and, in this case, preferred over the 500 years timeframe as used in other cultural perspectives (Goedkoop et al. 2013). The hierarchist model is also known as the default model and therefore often applied (Consultants 2016b).

As stated above, the midpoint assessment method considers 18 environmental indicators[3]. Often, not all of those impacts are considered in an LCIA. The reason is that some environmental impacts may generally be infinitesimally small, or simply not relevant in comparison with other environmental impacts. Furthermore, the focus of comparative studies can be put on on environmental impacts that have significant differences, which may be the reason to favor one product over another. All impact categories have been considered in this report; closer examination can be found in the chapter Results. For more detailed information about the impact categories that have been identified by ReCiPe midpoint please refer to the text by Goedkoop et al., 2013.

## 3.5. Normalization and weighting

No weighting has been used in this project, however, normalization is used when displaying the results. The normalization used in this report is done through SimaPro. The LCA conducted in this report is a comparative one and normalization is not needed in order to see which of the two alternatives that have the most impact. It is however relevant to display normalized results in order to see which environmental impact that is the most significant one. By using normalization it becomes visible how large the different impact categories are in relation to one and other. This is particularly interesting since it is desirable to know which of the given environmental impacts that are the most concerning, or in other words the what environmental impacts that are the largest. The downside with using normalization is that it is normalized to a standard European citizen, due to this it is not possible to see the absolute value of all the impacts. European citizens have for example low impacts to ozone and high impacts on freshwater, so if a potential outcome of the results would follow that pattern then it is hard to say how large the impacts actually are.

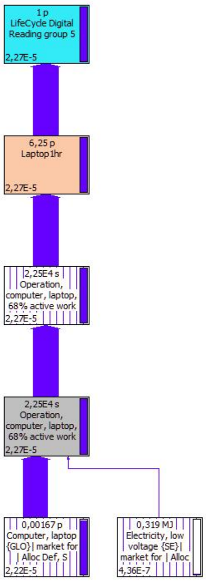
# 4. Life Cycle Inventory Analysis

## 4.1. Process Flowcharts

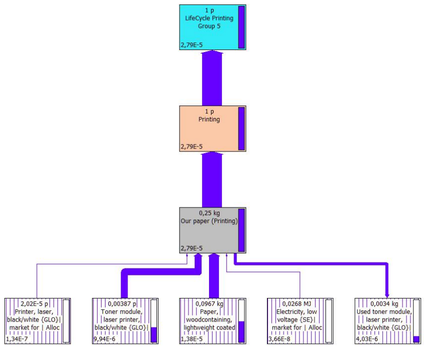
After choosing the components of the SimaPro Database that best fit the data requirements - partially altering them in order to better suit the needs of this report - the following process network graphs could be created to illustrate the exact processes included for this project.

For a more detailed explanation of model usage and data alterations, refer to section 4.2 below.

[3] 1) Fossil Depletion, 2) Metal Depletion, 3) Water Depletion, 4) Neutral Land Transformation, 5) Urban Land Occupation, 6) Agricultural Land Occupation, 7) Marine Ecotoxicity, 8) Freshwater Ecotoxicity, 9) Terrestrial Ecotoxicity, 10) Marine Eutrophication, 11) Freshwater Eutrophication, 12) Terrestrial Acidification, 13) Ionising Radiation, 14) Particulate Matter Formation, 15) Photochemical Oxidant Formation, 16) Human Toxicity, 17) Ozone Depletion, 18) Climate Change.




(a) Process network visualization of the digital reading process, SimaPro




(b) Process network visualization of the paper-based reading process, SimaPro

Figure 3.: .

## 4.2. Data

In order to carry out both parts of the LCA, data on various processes and materials was needed. In general, materials and energy were derived and adapted from Ecoinvent 3.3 database as implemented in SimaPro 8; an overview of model processes and materials used can be found in Table 4.1.

Data needed to solve allocation issues and to determine quantities of materials needed was generally derived from own research. An overview of these data points can be found in Table 4.2. Please find detailed descriptions of data collection methods, calculations, and edits of model data below.

| Component [Unit] | Input Process in SimaPro 8 | Quantity |
|---|---|---|
| Computer [1 piece] | Computer, laptop / GLO | 0,00167 pieces |
| Electricity [1 MJ] | Electricity, low voltage / SE | 0,319 MJ (digital reading)<br>0,0268 MJ (printing) |
| Printer [1 piece] | Printer, laser, black/white / GLO | 2,02E-5 pieces |
| Toner [1 piece] | Toner module, laster printer, black/white / GLO | 0,00387 pieces |
| Paper [1 kilogram] | Paper, wood containing, lightweight coated | 0,0967 kg |

Table 4.1.: Specific datasets from SimaPro database used

| Data needed | Reason |
|---|---|
| Reading Speed | Determines time spent reading |
| Words per Page | Determines time spent reading |
| Energy consumption of laptop per hour | Determines total energy consumption |
| Lifetime of laptop | Resolution of multi-function allocation issue |
| Type of paper | Material used for FU |
| Amount of energy needed for printing | Determines total energy consumption |
| Swedish waste scenario for paper | Process used for FU |

Table 4.2.: Specific data collected through own research

### 4.2.1. Digital reading

In order to determine the total environmental impacts of the digital reading process, it was necessary to determine both the total energy usage during the digital reading and the part of the laptop “used up” for this reading process.

The first of these items was calculated by researching the average number of words on a page of scientific article, combined with the average reading speed of a university level student and the energy consumption of a modern-day laptop per unit of time.

The second issue, an allocation problem, was solved using a technique similar to that employed in Ahmadi Achachlouei 2015: By estimating the total lifetime of the device, then calculating the fraction of time the reading employs of that total available time.

**Number of words per page**
In order to determine the average number of words per A4 page of academic writing, some of the authors went through a sample of reading they obtained for several KTH courses. The results of this research can be found in Appendix A. It appears that, on average, there are approximately 750 words on a single page of a scientific article (already accounting for graphs and tables). Of course, this calculation does not take into account variation between research fields, types of articles, et cetera.

**Average reading speed**
The question of average reading speeds was derived mostly from academic sources and reviews; in addition, the authors performed tests on themselves and fellow students to verify the accuracy of the data thus collected. According to data found in the literature[1], it appears that a reading rate of about 200 words per minute (wpm) is reasonable for university students thoroughly reading new material (without having to memorize or study it). In comparison, 450 wpm seem to be possible for a faster re-read of known material, without skimming over the text. All of these data points were originally collected for paper-based reading; however, we had to assume similar speeds are possible on screen for users accustomed to using this medium for reading.

**Energy consumption of a laptop**
Through background research, it was concluded that a modern laptop uses, on average, about 5W to 15W of electricity. Since this was consistent with data used in SimaPro, we did not change the data in the model.

[1] Also compare Carver 1992, Carver 1997, Readingsoft.com 2015, Benjamin and Gaab 2012 and Primativo et al. 2016.

**Lifetime of a laptop**
According to background research research done, it appears one can assume a laptop to remain operational for around four years. This number seems consistent with those used by large IT companies: Lenovo assumes a four year usage in their calculation of carbon footprints[2], while HP guarantees functionality of their new devices for at least 3 years[3].

**Laptop allocation** Assuming the laptop is used 66% of the time over a four year period, we arrive at 23 376 hours of total usage. Given that we read for 6.25 hours when reading slowly (see numbers above), reading 100 pages of an A4 PDF would use up 0.026736824% of the laptop.

### 4.2.2. Process of printing

In the SimaPro database there is a process named "Printed paper". It is made to simulate the impacts of 1 kg of printed paper. This process had been used as the basis for printing papers, however some inputs have been modified. The four inputs to printing are; paper, electricity, toner and printer. More details about these inputs can be viewed below. It is assumed that the allocation for all represented inputs are correctly managed in SimaPro, for example it is assumed that the SimaPro printing process uses a standard and legitimate amount of toner and electricity for each kilo of printed paper.

**Paper**
The functional unit 100 pages represents 50 sheets of paper with a total weight of 0,25 kg due to the facts that one sheet of paper has a weight of 5 grams and it is assumed that the paper is printed on both sides. The weight of 5 grams per A4 sheet was decided upon after investigation the weight of paper used for printing at KTH and after looking into what paper that is used in the process of printing in SimaPro. There are many different available paper types in the SimaPro database, the type of paper chosen was wood-containing paper that is light-weight coated. This was chosen partly because it was the default choice for the printing process and partly because this was one of the few options that was not already printed on or had a high concentration of recycled paper fibers in it. It was desirable to have a paper without recycled content because a review of the paper used for printing at KTH shows that it does not contain recycled material. The paper used here include extraction of raw materials, transportation of raw materials to production site and production. No distribution transportation, user phase or end-stage is included. It is considered that a paper does not have any extra environmental impact during its user phase so it will be ignored. The distribution of the paper, the transportation from production to the selling warehouse, is not included either. Lack of data regarding paper distribution lead to this step being excluded from the life cycle analysis. The end-stage or waste scenario of the paper can be viewed below under the heading "waste scenario for paper".

**Electricity**
The electricity input in the printing model from SimaPro has been modified, the input has been set to the Swedish electricity mix instead of the global electricity mix. This modification was carried out to fit the given scenario geographically, the printing takes place at KTH which is located in Stockholm, Sweden. The amount of electricity required is given in the SimaPro process of printing, this number has not been changed due to lack of data. If data had been

[2]http://www.lenovo.com/social_responsibility/us/en/pcf/PCF_ThinkPad_E560.pdf
[3]http://store.hp.com/wcsstore/hpusstore/pdf/EliteBook_%201040G3.pdf

available it would have been interesting to conduct a sensitivity analysis with the electricity as the changing parameter. Unfortunately this is not possible with current data.

**Toner**
The toner used in the process of printing is the default toner used in the available printing process in SimaPro. Both toner and amount of toner has remained unchanged from the original model. To not edit the toner input can be motivated by the lack of data. Production, transportation, distribution and recycling of the toner container/ module are all included in the dataset in SimaPro.

**Printer**
One of the largest data errors in this process is that the printer available in SimaPro does not exactly fit the given scenario and that the model is outdated. This means that the printer in SimaPro is made for home-use or small office use while the printer that were desirable to include are a very large office printer like the ones available in the computer halls at KTH. The printer itself is also from the year of 2004 and thanks to rapid technological development much has happened to printing technology during the last 12 years. For example; wireless chip, efficiency with toner and electricity. The use of the printer in SimaPro is however rather accurate for the KTH scenario: The given lifetime of the printer available in SimaPro is 4 years. The four years represents 20 000 pages printed per month which adds up to 960 000 printed pages during the four year lifetime, this represents 4800 kg of printed paper. This is similar to the usage of a KTH-printer.

The production, transportation and distribution of the printer is included in the model in SimaPro. The allocation of the printer per kg of printed paper that is used in SimaPro is assumed to be correct. It is simply allocated by kg of printed paper where one kilo of paper represents 200 pages due to the assumption that one A4 paper has a weight of 5 grams. There is no waste scenario for the printer included in SimaPro, however due to the very small allocation of the printer for printing the functional unit it is not deemed necessary to include.

### 4.2.3. Waste scenario for paper

According to the Swedish Environmental Protection Agency approximately 75% out of all office papers goes to recycling. Schools and universities are however not included in the investigation leading up to these numbers. It is however assumed that students' recycling behavior is more similar to office behavior rather than the behavior of recycling paper packages or newspapers. These three categories were the only available paper recycling scenarios from the Swedish Environmental Protection Agency (Naturvårdsverket 2012).

The data used for the waste scenario is not a perfect match for this specific scenario. The data used for incineration is taken from Canada since there was no available data for Sweden. Canada (without Quebec) was chosen over the global data due to Canada being a country with similar statistics and development as Sweden. The data for paper recycling is global data and is the only available dataset for recycling paper in SimaPro. Data gathered from Sweden would of course make this waste scenario more reliable.

There is, as previously mentioned, a waste scenario for the toner module included in this model as well. However, the printer's waste scenario has been excluded as many students use the available printers at the university and don't own a printer themselves. Accordingly, the disposal of a printer couldn't be allocated to a single student as it is necessary when considering the functional unit.

# 5. Life Cycle Interpretation

For digital reading, it seems that the biggest normalized environmental impacts are with respect to human toxicity, freshwater eutrophication, as well as freshwater and marine ecotoxicity. In each of these four impact categories, the total impacts from reading 100 pages of text on-screen surpass 0.15% of the total impact an average EU citizen has over the course of one year. For marine ecotoxicity, this value almost reaches 0.3%.

Since much of the data used for the calculation pertaining to digital reading (average reading speeds, average number of words per page, energy consumption of a laptop while reading) is little better than educated estimates, the authors decided to carry out a sensitivity analysis. This analysis yielded astonishing results: when reading at faster speeds - 450 wpm as opposed to 200 wpm, effectively halving the time spent reading - the impact on marine ecotoxicity decreases from 0.0256 kg 1,4-dichlorobenzene (1.4 DB) equivalents to 0.01138 kg 1.4 DB equivalents. Similarly, re-reading the document a second time - thus effectively doubling the time spent reading - also doubles the estimated impact (0.05123 kg 1.4 DB equivalents). Similar results were obtained for all impact categories; please refer to Appendix B for further details.

On first sight, this might lead to the faulty conclusion that most of the impact of digital reading stems from the usage phase, and thus, from the electricity consumption. This would, however, be at odds with the overall environmental impact estimates of the different assemblies as depicted by a process network visualization as shown by SimaPro 3b. This mismatch is due to a simple methodological difficulty: since the allocation of the multi-function device (the laptop) was estimated by using the percentage of lifetime spent on a function, doubling the reading time doubles the "part" of the laptop allocated to reading as well as the electricity consumption. In order to carry out a more detailed analysis of hotspots in the digital reading life cycle, a different allocation method would therefore have to be chosen.

The most important normalized impact categories concerning the printing are; freshwater eutrophication, human toxicity, freshwater ecotoxicity, marine ecotoxicity and natural land transformation. The four highest impacts are the same for the digital reading. This can be seen when studying Figure B and exact number can be found in Appendix B.

Out of these the digital reading have a higher score for every impact. In Figure 3b it be seen that the paper has the largest environmental impact for the printing process and that the toner has the second largest. The significant impact from paper can be explained by the complexity of the paper industry and the land transformation it requires. The very low impact from the printer can be explained by the chosen allocation method. Only 0,00806% of the printer is used to print the 100 pages that are the functional unit in this report. The impact from the electricity is also very low. This can be explained partly by the fact that the Swedish electricity mix has a high share of renewable and nuclear energy and very little fossil energy sources. The second part of the explanation is that very little energy is required to print 100 pages according to this model.

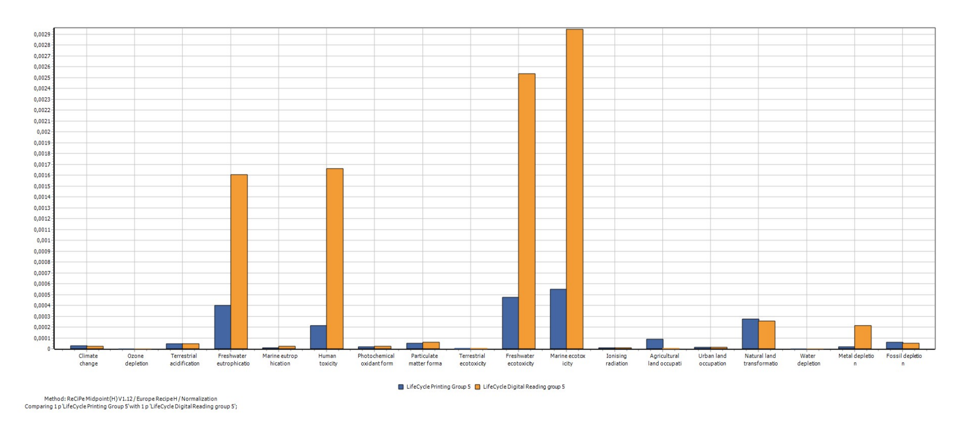



Figure 4.: Comparative normalized results of digital and paper-based reading

# 6. Conclusions and Recommendations

The goal of this study was to find out whether there is a difference in impacts when reading on a laptop or printing the required literature. Thereby using different reading speeds, as to visualise possible differences in comprehending the literature. We cannot say which impact category is the most important, because we cannot do the weighting step.

As stated above, the largest impacts from digital reading are found in the categories human toxicity, freshwater eutrophication, as well as freshwater and marine ecotoxicity. Those are the same categories where the biggest differences between both LCAs can be found.

The impact coming from digital reading in the category freshwater eutrophication is four times bigger than from on paper reading. Freshwater eutrophication happens due to the enrichment of nutrients in freshwater. Especially on the european continent, eutrophication considers a problem, as it's level of pollution is more sever than due to toxic substances. Relevant substances that cause the pollution include especially nitrogen and phosphorus compounds which favours, among other impacts, the growth of biomass. The nutrient supply on agricultural land and industrial wastewater treatment plants have been found being two of the biggest contributors to freshwater eutrophication. (Goedkoop et al 2013) The impact coming from digital reading in the category human toxicity is about seven times bigger than from on paper reading. In addition, impacts coming from digital reading in the category freshwater and marine ecotoxicity are about five times bigger than from on paper reading. Those impacts are characterized by the environmental persistence, accumulation in the human food chain and toxicity of a certain chemical. Summarized, those impact categories account the accumulation of harmful chemicals in different systems.(Goedkoop et al 2013)

As above mentioned, the presented impacts are tremendously bigger for the digital reading LCA. Especially, toxic impacts as human toxicity, freshwater and marine ecotoxicity can be led back to the bigger use of metals (Dong 2013) in the production of the computer and its disposal scenario than in the production of the printer, toner powder and paper. The extraction of metals, e.g. rare earth elements, constitute several problems. As the required metals usually don't occur in a pure state, they first have to be extracted with the use of toxic chemicals and are later separated in an elaborate process (Burrows 2016) . This might be the reason, why toxic substances and metals end up in freshwater and marine systems as well as in the human body. The breach of a dam of an aluminum production in Hungary in the year 2010 has shown the dangerous and toxic effects of different metals and its production (Williams 2014). Consequently it is assumed that a cleaner way of extracting materials that are used in the computer and other electrical devices or the substitution could decrease the negative environmental impact in those categories. As Goedkoop et al. (2013) explains, eutrophication is caused, amongst others, by the treatment of industrial wastewater, the substitution of certain materials and substances throughout the production and a better disposal scenario for the computer may improve the impact in the category eutrophication.

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# A. Data Collection: Words per Page

| **Name of Text** | **Words per page** |
|---|---|
| Brugnach et al., 2008 | 646,32 |
| Carlsson-Kanyama et al., 2005 | 590,91 |
| Gunnarsson-Östling, 2011 | 855,56 |
| Hedren, 2009 | 820,00 |
| Sinha et al., 2016 | 757,45 |
| Höjer et al., 2011 | 689,66 |
| Wangel, 2011 | 896,21 |
| Wallgren and Höjer, 2009 | 1000,00 |
| von Oelrich et al., 2012 | 506,83 |
| Folke, 2006 | 830,00 |
| Folke et al., 2010 | 685,17 |
| Walker and Myers, 2004 | 619,02 |
| Marcus and Colding, 2014 | 750,00 |
| Sellberg et al., 2015 | 893,33 |
| Brand and Jax, 2007 | 610,00 |
| Fabinyi et al., 2014 | 1027,43 |
| Olsson et al., 2014 | 964,29 |
| *Average* | 750 |

# B. Results: Normalized Values for Digital and Paper-Based Reading

| Impact category | Unit | LCA digital Reading | LCA printing |
|---|---|---|---|
| Climate change | kg CO2 eq | 0,25408 | 0,31332 |
| Ozone depletion | kg CFC-11 eq | 3,16232E-08 | 2,95819E-08 |
| Terrestrial acidification | kg SO2 eq | 0,00152 | 0,00154 |
| Freshwater eutrophication | kg P eq | 0,00067 | 0,00017 |
| Marine eutrophication | kg N eq | 0,00023 | 0,00010 |
| Human toxicity | kg 1,4-DB eq | 1,04381 | 0,13427 |
| Photochemic | kg NMVOC | 0,00132 | 0,00096 |
| Particulate matter formation | kg PM10 eq | 0,00091 | 0,00076 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 5,22222E-05 | 3,8277E-05 |
| Freshwater ecotoxicity | kg 1,4-DB eq | 0,02789 | 0,00524 |
| Marine ecotoxicity | kg 1,4-DB eq | 0,02561 | 0,00476 |
| Ionising radiation | kBq U235 eq | 0,05788 | 0,06746 |
| Agricultural land occupation | m2a | 0,02921 | 0,40159 |
| Urban land occupation | m2a | 0,00613 | 0,00549 |
| Natural land transformation | m2 | 4,1721E-05 | 4,46965E-05 |
| Water depletion | m3 | 0,00308 | 0,00627 |
| Metal depletion | kg Fe eq | 0,15405 | 0,01385 |
| Fossil depletion | kg oil eq | 0,07939 | 0,09185 |